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Resistance Screening and Control Options for Glyphosate-Resistant Palmer Amaranth (Amaranthus palmeri) in Cotton (Gossypium hirsutum)

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Resistance Screening and Control Options for Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) in Cotton (*Gossypium hirsutum*)

Resistance Screening and Control Options for Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) in Cotton (*Gossypium hirsutum*)

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Crop, Soil, and Environmental Science

By

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University of Arkansas at Monticello
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ABSTRACT

In the mid-2000's, glyphosate-resistant Palmer amaranth biotypes began to emerge in many southern states. In 2006, glyphosate-resistant Palmer amaranth was identified in a field in Mississippi County, Arkansas. A greenhouse experiment was conducted in 2008 to screen Palmer amaranth accessions, collected in this survey, for glyphosate resistance. Inflorescence were collected from a total of 276 plants from fields were glyphosate failure occurred, representing 74 accessions in 14 counties, including Clay, Craighead, Crittenden, Greene, Jackson, Jefferson, Lawrence, Lee, Mississippi, Phillips, Poinsett, Randolph, St. Francis, and White Counties. Eight of the 74 accessions did not produce viable seed. In the greenhouse, 32 of the 66 Palmer amaranth accessions screened were at least 10% glyphosate-resistant. Two counties (Lee and St. Francis) contained Palmer amaranth accessions that were greater than 80% glyphosate-resistant. Every accession tested had at least one survivor following glyphosate at 0.86 kg ae/ha. Three field experiments were conducted in 2006 and 2007 to determine if preplant-applied fomesafen and postemergence-applied glufosinate would provide control of Palmer amaranth without causing cotton injury. A total of, 28 preplant (PPL) and preemergence (PRE) herbicide treatments and 27 herbicide programs were evaluated for Palmer amaranth control. The 28 PPL and PRE treatments were also evaluated for cotton injury. The 28 PPL and PRE treatments were fomesafen, flumioxazin, fluometuron, prometryn, diuron, and pendimethalin applied at four preplant timings (21, 14, 7, and 0 days). The Liberty Link herbicide programs, utilized glufosinate, *S*-metolachlor, fomesafen, fluometuron, prometryn, flumioxazin, diuron, and pendimethalin to control Palmer amaranth. At 7 days after emergence (DAE) of cotton, fomesafen applied at 0.21 and 0.28 kg ai/ha, flumioxazin at 0.071 kg ai/ha, prometryn at 1.12 kg ai/ha, diuron at 0.56 kg ai/ha, and pendimethalin at 1.12 kg ai/ha applied at

21, 14, 7, and 0 DPP all controlled Palmer amaranth 90 to 100%. Fomesafen at 0.21 kg ai/ha and flumioxazin at 0.071 kg ai/ha applied at 0 days prior to planting (DPP) reduced stand by 22 and 58%, respectively, when compared to those same treatments applied 21 DPP. Application timing was the only significant factor to affect cotton yield in the PPL and PRE study.

This thesis is approved for recommendation
to the Graduate Council.

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Introduction

Palmer amaranth is one of 60 *Amaranthus* species native to the Americas (Bridges 1992; Holm et al. 1977; Sauer 1967; Sweat et al. 1998) and shows more rapid growth initially than any other *Amaranthus* species (Sellers et al. 2003). Palmer amaranth is unique compared to many other *Amaranthus* species having a terminal spike inflorescence with male and female flowers on separate plants (dioecious) (Elmore1990; Keeley et al. 1987). Palmer amaranth is successful due to an extended emergence period that coincides with crop emergence and establishment, aggressive growth at high temperatures, prolific seed production (up to 600,000 seeds per female plant), high water use efficiency, and C_4 photosynthetic mechanism (Guo and Al-Khatib 2003; Horak and Loughlin 2000; Jha et al. 2007; Jha and Norsworthy 2009; Keeley et al. 1987; Massinga et al. 2003; Sellers et al. 2003; Uva et al. 1997; Weaver 1984).

Herbicidal control of Palmer amaranth in cotton was traditionally attained by implementing a complete program for weed control. These traditional programs included a soil-applied preplant incorporated, preplant (PPL) or preemergence (PRE) herbicide followed by a selective herbicide applied postemergence (POST) over-the-top or a post-directed herbicide early POST followed by a post-directed herbicide late POST and concluded 2 to 3 weeks later with a post-directed layby treatment (Faircloth et al. 2001; Jordan et al. 1997; Snipes et al. 1984). With the introduction of glyphosate-resistant cotton cultivars in 1997, the traditional approach was slowly replaced with glyphosate POST over-the-top applications (Faircloth et al. 2001; Givens et al. 2009; Jones and Snipes 1999; Patterson et al. 1998; Young 2006). Glyphosate tank mixed with residual herbicides has provided excellent weed control and high yields in cotton (Faircloth et al. 2001; Isgett et al. 1997; Keeton and Murdock 1997). However, glyphosate-only weed control programs present economic risks to cotton producers (Askew and Wilcut 1999; Faircloth et al. 2001), especially in the presence of glyphosate-resistant Palmer amaranth.

In 2012, 13 weed species were known to be glyphosate-resistant in the United States and 24 species worldwide (Heap 2012). Palmer amaranth resistance has been confirmed to four modes of action in the United States (Heap 2012). The continued use of glyphosate resulted in glyphosate-resistant Palmer amaranth in Georgia, Tennessee, North Carolina, and South Carolina (Culpeper et al. 2006; Scott et al. 2007; and York et al. 2007). In 2005, a single Palmer amaranth population in Mississippi county, Arkansas survived at least two applications of glyphosate at 0.86 kg ae/ha (Norsworthy et al. 2008; Scott et al. 2007; Scott and Smith 2006). Palmer amaranth was the third weed species in the state of Arkansas to evolve resistance to glyphosate (Scott et al. 2007). By 2009, 23 counties in Arkansas were known to be infested with glyphosate-resistant Palmer amaranth (Meier et al. 2009). Glyphosate-resistant Palmer amaranth has forced cotton producers to return to more traditional methods of control.

The objectives of this research were, to 1) collect and screen representative populations of Palmer amaranth that had escaped glyphosate applications during the growing season, 2) to document how many counties in Arkansas contained populations of glyphosate-resistant Palmer amaranth, 3) evaluate fomesafen and glufosinate for control of Palmer amaranth in cotton, and 4) identify injury to cotton, if any, caused by fomesafen applied preplant and preemergence.

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Chapter 1

Glyphosate Tolerance Screening of Escaped Palmer Amaranth (*Amaranthus palmeri*)

Glyphosate Tolerance Screening of Escaped Palmer Amaranth (*Amaranthus palmeri*)

Palmer amaranth is known to be prone to resistance. The continuous use of glyphosate from the late 90's to mid 2000's resulted in the evolution of glyphosate resistance in Palmer amaranth and other weed species in Georgia, Tennessee, North Carolina, and South Carolina**.** In 2005, a Palmer amaranth population in Mississippi County, Arkansas was reported as being glyphosate resistant. In 2007, 276 separate plants representing 74 Palmer amaranth accessions were collected in 14 counties across the state of Arkansas. All counties were located in the eastern row cropping region of the state. Palmer amaranth inflorescence were only collected from populations that were known survivors of a glyphosate application during the previous growing season. The greenhouse screening was performed in Monticello, Arkansas at the Southeast Research and Extension Center. Eight of the 74 accessions collected did not contain viable Palmer amaranth seed. Of the 66 accessions tested, 24 were 0.5 to 5, 9 were 6 to 10, 22 were 11 to 24, 8 were 25 to 50, and 3 were 69 to 86% glyphosate-resistant in 2007. All 14 counties had at least one plant that survived 0.86 kg ae/ha of glyphosate applied to cotyledon to 1-leaf Palmer amaranth. A single Palmer amaranth plant from Lee County produced progeny that were 96.5% glyphosate-resistant. Data from this 2007 survey suggested a highly evolving population of Palmer amaranth statewide, in terms of resistance to glyphosate. Overall the frequency of glyphosate resistance was highly variable at this time both within counties and accessions.

Nomenclature: Glyphosate; Palmer amaranth, *Amaranthus palmeri* S. Wats.

Key words: Glyphosate-resistant, Palmer amaranth.

Introduction

Amaranthus species are one of the most troublesome weeds in United States cropping systems. Palmer amaranth is one of 60 *Amaranthus* species native to the Americas (Bridges 1992; Holm et al. 1977; Sauer 1967; Sweat et al. 1998). Palmer amaranth starts germinating after accumulating 350 growing degree days (base temperature of 10 C) and shows more rapid growth initially than any other *Amaranthus* species (Sellers et al. 2003). Palmer amaranth is a small-seeded erect annual broadleaf weed that is very successful in the southern United States (Sellers et al. 2003; Uva et al. 1997). It is unique compared to many other *Amaranthus* species having a terminal spike inflorescence with male and female flowers on separate plants (dioecious) (Elmore1990; Keeley et al. 1987). Palmer amaranth is successful due to prolific seed production (up to 600,000 seeds per female plant), extended emergence period that coincides with crop emergence and establishment, high water-use efficiency, aggressive growth at high temperatures, and C_4 photosynthetic mechanism (Guo and Al-Khatib 2003; Horak and Loughlin 2000; Jha et al. 2007; Jha and Norsworthy 2009; Keeley et al. 1987; Massinga et al. 2003; Sellers et al. 2003; Uva et al. 1997; Weaver 1984). At maturity, Palmer amaranth can reach 1.8 to 2.4 m tall and competes with the crop for water, nutrients, and light (Barkley 1986; Guo and Al-Khatib 2003). Compared to other *Amaranthus* species, Palmer amaranth had the greatest values for plant volume, dry weight, leaf area, and 24 to 62% greater rate of height increase per growing degree day than any other *Amaranthus* species (Horak and Loughlin 2000).

By 2012, at least 13 weed species were known to be glyphosate-resistant in the United States and 24 species worldwide (Heap 2012). Palmer amaranth is one of the most resistant prone dicots, with confirmed resistance to four modes of action in the United States (Heap 2012). The continued use of glyphosate resulted in the evolution of glyphosate-resistant Palmer amaranth in Georgia, Tennessee, North Carolina, and South Carolina (Culpeper et al. 2006; Scott et al. 2007; York et al. 2007). In 2005, a single Palmer amaranth population in Arkansas survived at least two applications of glyphosate at 0.86 kg ae/ha (Norsworthy et al. 2008b; Scott et al. 2007; Scott and Smith 2006). Palmer amaranth was the fourth weed species in the state of Arkansas to evolve resistance to glyphosate (Scott et al. 2007).

The first glyphosate-resistant Palmer amaranth population was found in Mississippi County in northeastern Arkansas in 2005. After the discovery of this population, the question arose as to how wide-spread glyphosate-resistant Palmer amaranth was in the state. The objective of this research was to collect and screen representative populations of Palmer amaranth that had escaped glyphosate applications during the growing season and to document counties in Arkansas that contained populations of glyphosate-resistant Palmer amaranth.

Materials and Methods

A greenhouse screen of populations for resistance was conducted in 2008 at the University of Arkansas Southeast Research and Extension Center in Monticello, AR, to screen Palmer amaranth accessions, collected in Arkansas, for glyphosate resistance. In 2007, 276 separate plants representing 74 Palmer amaranth accessions were collected in 14 counties across the state of Arkansas (Figure 1.1). All counties were located in the eastern row cropping region of the state. While all county agents were invited to sample fields for this survey, presumably only those with perceived problems sampled fields or responded to the request. The number of accessions (fields sampled) collected from each county were Clay (3), Craighead (5), Crittenden (3), Greene (6), Jackson (5), Jefferson (10), Lawrence (5), Lee (4), Mississippi (11), Phillips (6), Poinsett (6), Randolph (3), St. Francis (5), and White (2) (Table 1.1). The accessions were collected from fields where glyphosate was used as a primary source of weed control, but failed to control Palmer amaranth at some level. Collection sites were chosen by growers, crop consultants, and county agents. Within each accession, the target number of individual plants collected was five. However, accessions with fewer plants surviving the glyphosate application were represented by less than five plants in some cases. The entire inflorescence was removed from each plant that was collected.

The Palmer amaranth inflorescence were collected and placed in numbered paper bags. The identification for each plant contained a number and a letter. The number represented the accession (1-74). The letter represented the individual plant (A, B, C, etc.). The paper bags containing the inflorescence were placed in a plant drier for 7 d at 30 C to remove excess moisture. To separate seeds from plant material, inflorescence were removed from the bags, hand threshed, and sifted through a series of sieves with opening sizes of 10, 12, and 14 mm. Once the samples had been sieved, the seed and small particle plant matter was placed in a Thomas Wiley laboratory reduction mill[1] to further separate plant matter from the seed. After being reduced in the mill, all remaining plant matter was removed using a custom designed and fabricated pneumatic seed cleaner[2].

Palmer amaranth seeds from each seed source were planted in two separate 52 by 38 by 10 cm flats filled with Pro-Mix potting media[3]. Flats were irrigated by sprinkler prior to seeding to ensure ideal germination conditions. A salt shaker was used to evenly disperse the Palmer amaranth seed in each flat. Greenhouse conditions included an ambient air temperature of 35 C (day) and 29 C (night) with a 16-h photoperiod supplemented with artificial light. Flats were thinned to a target population of 100 plants by using a grid 2 to 3 d after emergence. The plants left in the flat were located where the grid lines crossed. Total population tested over both trays ranged from 70 to 253 plants. Because of the large number of samples, seed from all locations could not be screened simultaneously. During each screening, previously confirmed glyphosate-resistant and susceptible biotypes were included for comparison, a method previously published by Culpepper et al. (2008). The glyphosate-resistant biotype was collected from Lincoln County. The Lincoln County accession had a field application of glyphosate at 7.7 kg ae/ha at 10 cm tall. The accession survived this rate and produced viable seed. The susceptible biotype was purchased from Azlin seed[4]. The resistant accession displayed 100% survival at 0.86 kg ae/ha while the susceptible accession displayed 0% survival (data not shown). These samples were included as a running check each time a batch of samples was screened in the greenhouse.

Seedlings (cotyledon to 1 leaf) were sprayed with 0.86 kg ae/ha of glyphosate[5] which represents a commonly used 1x field rate. Applications were made using a CO_2-pressurized backpack sprayer equipped with flat fan nozzles[6] delivering 112 L/ha at 310 kPa. The number of plants per tray was recorded at the time of application. Once the glyphosate application was made, flats were checked three times weekly for newly emerged Palmer amaranth by placing the grid back on the tray. If any new plants were found they were removed with forceps.

At 14 days after treatment (DAT), plants were evaluated as alive or dead. Plants were considered alive if they were erect and leaves contained green color. Plants living at 14 DAT were assumed to be resistant to a normal field rate of 0.86 kg ae/ha of glyphosate. The dead plants were assumed to be susceptible to a normal field rate of glyphosate. Percent survival was calculated by comparing the number of survivors to the total number of plants at the time of application. For seed from each glyphosate-resistant Palmer amaranth accession and plant, the proportion surviving was estimated and a 95% confidence interval was constructed under the assumption that survival for the offspring plant was independent of survival of all other offspring from the same seed source.

Results and Discussion

The two most common crops grown in fields where Palmer amaranth was sampled were cotton and soybean (Table 1.1). Palmer amaranth control was still attainable with glyphosate in many eastern Arkansas counties, the Arkansas River Valley region, and the South Eastern part of the state at the time of the survey; therefore, no accessions were obtained from those regions (Figure 1.1). Figure 1.1 presents a statewide view of the counties from which accessions were obtained. There were no reports of Palmer amaranth escaping glyphosate applications in many counties not included in the 2007 survey. Some counties not included were possibly in the beginning stages of glyphosate resistance. Growers and county agents were not concerned with the extremely small presumably non-threatening populations of glyphosate-resistant Palmer amaranth being observed. Many of the counties not sampled in 2007 were found to contain populations of Palmer amaranth surviving glyphosate applications in 2008 (Meier et al. 2009).

All 14 counties had at least one plant from one accession that survived 0.86 kg ae/ha of glyphosate applied to cotyledon to 1-leaf Palmer amaranth. The range of glyphosate resistance was highly variable within accessions and counties (Table 1.2). Percent survival varied greatly among progeny from a single accession. The average survival ranges for a single accession spanned as much as 70 or as little as 1% (Table 1.2). For example, plants from Poinsett County for accession 31 had survival rates ranging from 18 to 89%. However, in Mississippi County progeny from 26 of 31 plants tested contained 4% or less survivors. The highest survival rate

(96.5%) in a single Palmer amaranth progeny was collected in Lee County. The accession that included this extremely resistant progeny contained other progeny as low as 76.5% resistant.

Eight of the 74 accessions sampled contained no viable seed. Of the remaining 66 Palmer amaranth accessions, 32 were at least 10% glyphosate-resistant (Table1.3). Of the 66 accessions tested, 24 were 0.5 to 5, 9 were 6 to 10, 22 were 11 to 24, 8 were 25 to 50, and 3 were 69 to 86% glyphosate-resistant in 2007. Two counties (Lee and St. Francis) had high frequency of glyphosate-resistant Palmer amaranth. Both counties contained accessions that were greater than 80% glyphosate-resistant. The average accession survival within counties were Clay (1.0 to 13.5%), Craighead (6.7 to 17.7%), Crittenden (13.2 to 14.1%), Greene (0.2 to 2.5%), Jackson (2.2 to 32.3%), Jefferson (2.5 to 18.0%), Lawrence (9.4 to 24.0%), Lee (23.8 to 83.0%), Mississippi (0.2 to 5.8%), Phillips (7.3 to 29.1%), Poinsett (5.8 to 36.7%), Randolph (6.0 to 16.0%), St. Francis (8.0 to 85.1%), and White (0.4 to 0.5%) (Table1.3).

The frequency of glyphosate resistance between Palmer amaranth plants in a single accession (Table 1.2) and accessions within a single county (Table 1.3) were both highly variable, in this 2007 screening. The plant to plant variability of glyphosate resistance within an accession was very similar to the mean glyphosate resistance for all plants in the same accession. This is likely due to Palmer amaranth being dioecious, having male and female plants, and cross pollinating. This data implies that Palmer amaranth was in various stages of glyphosate resistance depending on the geographic location of the accession. It also implies that each accession was becoming glyphosate-resistant independent of other accessions within the same county. This is likely due to the selection pressure caused by herbicide programs used to control Palmer amaranth in cotton.

Previously, in 2005, a single Palmer amaranth population in Mississippi County was found to be glyphosate-resistant (Norsworthy et al. 2008b; Scott et al. 2007; Scott and Smith 2006). This was the first known case of Palmer amaranth being glyphosate-resistant in the state. Although the 2005 population was not included in the 2007 survey, 11 other accessions where included. The accessions from Mississippi County ranged from 0.2 to 6.8% glyphosate-resistant. The 2005 accession was 27% resistant to a 0.86 kg ae/ha glyphosate application (Norsworthy et al. 2008b). The accessions in this survey were not as highly resistant as the original 2005 accession.

Data from this 2007 survey suggested a highly evolving population of Palmer amaranth in Northeastern Arkansas, in terms of resistance to glyphosate. Overall the frequency of glyphosate resistance was highly variable at this time both within counties and accessions. Similar results were found when glyphosate screening was done on Palmer amaranth populations in Georgia, North Carolina, Tennessee, and Arkansas (Culpepper et al. 2008; Steckel et al. 2008; Norsworthy et al.2008a). In Georgia and North Carolina, 71 of 136 and 49 of 288 Palmer amaranth accessions survived a 0.84 kg ae/ha glyphosate application, respectively (Culpeper et al. 2008). In Tennessee, glyphosate resistance within Palmer amaranth accessions in a county ranged from 0 to 20% (Steckel et al. 2008). In Arkansas, glyphosate resistance within Palmer amaranth accessions in a county ranged from 0.2 to 11.8% (Norsworthy et al. 2008a). This 2007 Arkansas survey shows the same trends as previous Georgia, North Carolina, Tennessee, and Arkansas surveys have shown.

This survey provided a brief warning of Palmer amaranth infestation, which was to come. Glyphosate-resistant Palmer amaranth control options in cotton and soybean were immediately established and presented to Arkansas growers. A large educational effort was initiated because of the early warning this 2007 survey provided. By 2009, there were 23 counties in Arkansas known to be infested with glyphosate-resistant Palmer amaranth (Meier et al. 2009; Norsworthy et al. 2008b). Glyphosate-resistant Palmer amaranth is now present in all row cropping counties in Arkansas. This 2007 survey data captured a moment in time when glyphosate resistance was rapidly evolving in Arkansas row crop areas, but had not yet reached all counties and fields. If as little as 1% of a Palmer amaranth population is glyphosate-resistant, zero tolerance or complete control is essential. If a Palmer amaranth plant produces 600,000 seed per season and 1% survived, then 6,000 would be resistant. A glyphosate-based herbicide program used the following year would likely fail. Unfortunately, for many Arkansas soybean and cotton producers this was the case in 2008 and 2009.

Sources of Material

[1] Thomas Wiley laboratory reduction mill, Thomas Scientific P.O. Box 99Swedesboro, NJ 08085 U.S.A.

[2] Pneumatic seed cleaner, University of Arkansas 1408 Scogin Dr. Monticello, AR 71656.

[3]Pro-Mix potting media, Premier Tech Horticulture 127 South Fifth Street, #300 Quakertown , PA 18951.

[9] Azlin Seed, Azlin Seed Service 112 Lilac Drive Leland, MS 38756-3012

[5] Glyphosate herbicide, Monsanto Co. 800 North Lindberg Blvd., St. Louis MO 63167.

[6] GreenLeaf Airmix 11015 flat-fan spry tips, GreenLeaf Technologies P.O. Box 1767, Covington, LA, 70434.

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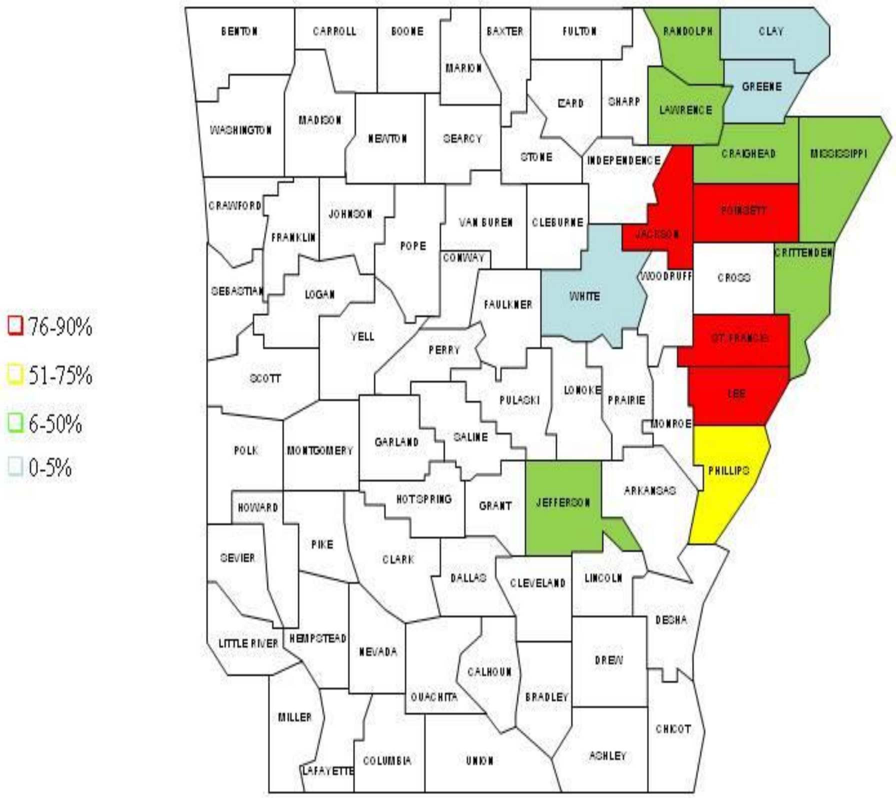

Figure 1.1 Percentage of Palmer amaranth accession progeny resistant to glyphosate (0.86 kg ae/ha) found in Arkansas counties – 2007. Color codes are based on the highest percentage of resistance found in a single plant. Counties with no color were not sampled.

Table 1.1 Palmer amaranth (*Amaranthus palmeri*) accessions (2006/2007) listed by county, crop, and the coordinates from which they were collected in the order they were received.

Accession	County	Crop	Latitude	Longitude
1	Lee	Cotton	N34 44.290	W90 37.833
2	Phillips	Cotton	N34 35.936	W90 45.800
3	Lee	Cotton	N34 41.460	W90 37.902
4	Lee	Soybean	N34 41.596	W90 38.873
5	Lee	Cotton	N34 45.524	W90 39.611
6	St. Francis	Cotton	N34 55.270	W90 38.500
7	St. Francis	Cotton	N34 57.180	W90 39.450
8	St. Francis	Cotton	N34 57.000	W90 47.220
9	St. Francis	Cotton	N34 56.030	W90 48.240
10	St. Francis	Cotton	N36 06.380	W90 39.010
11	Greene[1]	Soybean		
12	Greene	Soybean		
13	Greene	Soybean		
14	Greene	Soybean		
15	Greene	Soybean	N35 59.193	W90 24.436
16	Greene	Soybean		
17	Phillips	Soybean	N34 29.558	W90 63.341
18	Phillips	Cotton	N34 30.438	W90 54.299
19	Phillips	Soybean	N34 37.312	W90 54.062
20	Phillips	Soybean	N34 35.053	W90 46.073
21	Phillips	Cotton	N34 32.094	W90 54.122
22	Lawrence	Soybean	N36 08.258	W91 01.496
23	Lawrence	Soybean	N36 00.152	W90 54.328
24	Lawrence	Soybean	N36 00.213	W91 04.960
25	Lawrence	Unknown	N36 02.401	W91 03.016

[1] Coordinates were not provided

Table 1.1 cont. Palmer amaranth (*Amaranthus palmeri*) accessions (2006/2007) listed by county, crop, and the coordinates from which they were collected in the order they were received.

Accession	County	Crop	Latitude	Longitude
26	Lawrence	Soybean	N35 59.592	W90 57.140
27	Poinsett	Soybean	N35 41.537	W90 39.582
28	Craighead	Soybean	N35 48.396	W90 55.733
29	Craighead	Soybean	N35 48.396	W90 55.733
30	Poinsett	Cotton	N35 40.668	W90 37.159
31	Poinsett	Soybean	N35 31.749	W90 44.747
32	Poinsett	Cotton	N35 41.542	W90 36.760
33	Craighead	Soybean	N35 51.266	W90.35.833
34	Craighead	Soybean	N35 51.157	W90 43.818
35	Craighead	Soybean	N35 50.848	W90 50.277
36	Poinsett	Soybean	N35 41.333	W90 32.673
37	Poinsett	Cotton	N35 37.559	W90 30.041
38	Mississippi	Cotton	N35 30.149	W 90 08.629
39	Mississippi	Soybean	N35 57.334	W89 45.563
40	Mississippi	Soybean	N35 41.707	W90 02.234
41	Mississippi	Soybean	N35 33.345	W90 08.602
42	Mississippi	Unknown	N35 44.280	W89 59.989
43	Mississippi	Soybean	N35 27.979	W90 02.201
44	Mississippi	Unknown	N35 28.998	W90 09.115
45	Mississippi	Soybean	N35 33.290	W90 07.483
46	Mississippi	Soybean	N35 50.501	W90 01.049
47	Mississippi	Cotton	N35 26.793	W90 07.199
48	White	Soybean	N35 07.852	W91 35.216
49	White	Soybean	N35 19.765	W91 25.809
50	Clay[1]	Cotton		

[1] Coordinates were not provided

Table 1.1 cont. Palmer amaranth (*Amaranthus palmeri*) accessions (2006/2007) listed by county, crop, and the coordinates from which they were collected in the order they were received.

Accession	County	Crop	Latitude	Longitude
51	Clay[1]	Cotton		
52	Clay	Cotton		
53	Mississippi	Unknown		
54	Randolph	Soybean	N36 13.403	W90 53.849
55	Randolph	Soybean	N36 08.349	W90 55.279
56	Randolph	Soybean	N36 10.422	W90 59.407
57	Jefferson	Unknown	N34 16.047	W91 58.848
58	Jefferson	Unknown	N34 16.506	W91 56.293
59	Jefferson	Unknown	N34 16.831	W91 56.358
60	Jefferson	Cotton		
61	Jefferson	Soybean		
62	Jefferson	Unknown	N34 14.430	W91 50.759
63	Jefferson	Unknown		
64	Jefferson	Cotton		
65	Jefferson	Cotton		
66	Jefferson	Cotton		
67	Jackson	Unknown	N35 35.027	W 91 14.071
68	Jackson	Unknown	N35 41.938	W91 18.007
69	Jackson	Unknown	N35 32.966	W91 13.984
70	Jackson	Unknown	N35 37.150	W91 20.281
71	Jackson	Unknown	N35 33.410	W91 15.305
72	Crittenden	Cotton	N35.39255	W90.21693
73	Crittenden	Soybean	N35.31307	W90.13017
74	Crittenden	Cotton	N35.29385	W90.18326

[1] Coordinates were not provided

Table 1.2 The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
1	Lee	1A	24.5	18.6-30.5
		1B	47.0	40.1-53.9
		1C	34.5	27.9-41.1
		1D	45.8	38.7-52.9
		1E	53.5	46.6-60.4
2	Phillips	2A	34.5	27.9-41.1
		2B	8.5	4.6-12.4
		2C	38.0	31.3-44.7
		2D	19.0	13.6-24.4
		2E	11.5	7.1-15.9
3	Lee	3A	77.0	71.2-82.8
		3C	96.5	94.0-99.1
		3D	76.5	70.6-82.4
		3E	81.9	76.7-87.1
4	Lee	4A	80.0	74.5-85.5
		4B	64.5	57.8-71.1
		4D	61.5	54.8-68.2
		4E	71.5	65.2-77.8
5	Lee	5A	24.0	16.5-31.5
		5B	15.5	10.5-20.5
		5E	32.0	25.5-38.5
6	St. Francis	6A	26.5	18.5-34.5
		6B	16.5	11.4-21.6
		6C	24.5	18.5-30.5
		6D	34.2	28.1-40.4
7	St. Francis	7A	3.8	0.5-7.2
		7B	4.0	1.3-6.7
		7C	13.0	8.3-17.7
		7D	9.5	5.4-13.6
8	St. Francis	8A	82.5	77.3-87.6
		8B	87.7	83.3-92.3

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.

[b] Confidence intervals show the % survival range for a single progeny.

Table 1.2 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
9	St. Francis	9A	25.7	15.5-36.0
		9B	53.8	46.3-61.4
		9C	28.7	21.4-35.9
		9D	10.7	5.2-16.1
10	St. Francis	10A	50.8	41.8-59.9
		10B	6.7	3.2-10.2
		10C	28.1	21.6-34.6
		10D	39.8	33.0-46.6
11	Greene	11A	-[1]	-
12	Greene	12A	-	-
13	Greene	13A	0.2	0.0-1.8
14	Greene	14A	2.5	0.3-4.7
15	Greene	15A	-	-
16	Greene	16A	-	-
17	Phillips	17A	8.0	4.2-11.8
		17B	7.0	3.5-10.5
		17C	17.0	11.8-22.2
		17D	37.7	30.8-44.6
		17E	31.5	25.1-37.9
18	Phillips	18A	14.0	9.3-18.7
		18B	53.2	46.3-60.1
		18D	28.5	22.2-34.8
		18E	21.0	15.4-26.7
19	Phillips	19A	10.0	5.8-14.2
		19B	19.2	13.7-24.7
		19C	13.0	8.3-17.7
		19D	13.5	8.8-18.2
		19E	3.0	0.6-5.4
20	Phillips	20A	8.0	4.2-11.8
		20B	5.5	2.3-8.7
		20C	10.0	5.9-14.1
		20D	2.5	0.3-4.7
		20E	10.5	6.3-14.8

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.
[b] Confidence intervals show the % survival range for a single progeny.

[1] Palmer amaranth seed not viable in this accession

Table 1.2 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
21	Phillips	21A	19.2	14.0-24.5
		21B	9.4	5.4-13.4
		21C	33.3	27.0-39.7
		21D	15.5	10.8-20.2
		21E	6.2	2.9-9.4
22	Lawrence	22A	6.2	2.9-9.4
		22B	17.1	12.2-22.1
		22C	8.0	4.3-11.6
23	Lawrence	23A	10.5	6.3-14.6
		23B	9.9	5.8-14.0
		23C	7.8	4.2-11.5
24	Lawrence	24B	9.9	5.9-13.9
		24C	36.8	30.6-42.9
25	Lawrence	25A	25.4	19.4-31.3
		25B	1.9	0.1-3.8
		25C	21.9	16.3-27.5
26	Lawrence	26A	15.0	10.2-19.8
		26B	9.6	5.7-13.6
		26C	11.8	7.5-16.2
27	Poinsett	27A	43.8	36.9-50.6
		27B	5.7	2.6-8.8
		27C	15.2	10.3-20.0
		27D	6.4	3.0-9.7
		27E	3.3	0.9-5.8
28	Craighead	28A	4.2	1.5-7.0
		28B	18.6	13.3-23.8
		28C	6.3	3.0-9.7
		28D	30.4	24.8-36.1

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.
[b] Confidence intervals show the % survival range for a single progeny.

Table 1.2 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
29	Craighead	29A	8.1	4.4-11.8
		29B	1.5	0.0-3.1
		29C	4.9	1.9-7.8
		29D	0.5	0.0-1.4
		29E	5.4	2.3-8.5
30	Poinsett	30A	3.0	0.6-5.3
		30B	7.9	4.4-11.4
		30C	10.0	5.8-14.2
		30D	5.8	2.6-9.0
		30E	2.6	0.5-4.6
31	Poinsett	31A	18.1	13.1-23.2
		31B	89.4	85.4-93.5
		31C	21.0	15.4-26.6
		31D	34.3	27.8-40.9
		31E	18.5	13.1-23.9
32	Poinsett	32A	14.9	10.1-19.7
		32B	20.9	15.4-26.3
		32C	7.7	4.1-11.3
		32D	13.5	9.0-17.9
		32E	54.0	47.1-60.9
33	Craighead	33A	16.5	11.4-21.6
		33B	28.2	22.1-34.3
		33C	10.1	6.1-14.1
		33D	16.5	11.7-21.4
34	Craighead	34A	25.1	19.5-30.7
		34B	14.6	10.0-19.2
		34C	10.8	6.7-14.9
		34D	11.0	6.7-15.2
		34E	7.3	3.9-10.8

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.
[b] Confidence intervals show the % survival range for a single progeny.

Table 1.2 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
35	Craighead	35A	6.6	3.3-10.0
		35B	14.2	9.6-18.9
		35C	3.9	1.2-6.5
		35D	4.8	1.9-7.8
		35E	3.8	1.2-6.4
36	Poinsett	36A	13.6	9.0-18.2
		36B	60.7	54.0-67.4
		36C	6.3	3.0-9.6
		36D	1.4	0.0-3.0
		36E	2.8	0.6-5.1
37	Poinsett	37A	33.5	27.1-39.8
		37C	11.9	7.4-16.5
		37D	3.4	0.9-5.9
		37E	7.5	4.0-11.1
38	Mississippi	38D	0.5	0.0-1.5
		38E	8.5	4.6-12.4
39	Mississippi	39A	4.0	1.3-6.7
		39C	0.5	0.0-1.5
40	Mississippi	40A	33.5	27.0-40.0
		40B	0.5	0.0-1.5
41	Mississippi	41A	11.0	6.7-15.3
		41B	2.0	0.1-3.9
		41C	4.0	1.3-6.7
		41E	2.5	0.3-5.0
42	Mississippi	42E	1.0	0.0-2.4
43	Mississippi	43A	1.0	0.0-2.4
		43B	0.5	0.0-1.5
		43C	1.5	0.0-3.2
		43D	0.5	0.0-1.5

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.
[b] Confidence intervals show the % survival range for a single progeny.

Table 1.2 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
44	Mississippi	44B	2.5	0.3-4.7
		44C	3.0	0.6-5.4
45	Mississippi	45B	1.0	0.0-2.4
		45E	0.5	0.0-1.5
46	Mississippi	46C	2.5	0.3-4.7
		46E	2.0	0.1-3.9
47	Mississippi	47A	2.0	0.1-3.9
		47B	1.0	0.0-2.4
		47C	3.0	0.6-5.4
		47D	0.5	0.0-1.5
		47E	0.5	0.0-1.5
48	White	48A	1.0	0.0-2.4
		48D	0.5	0.0-1.5
49	White	49A	0.5	0.0-1.5
		49D	0.5	0.0-1.5
50	Clay	50A	1.0	0.0-2.4
51	Clay	51A	7.0	3.5-10.5
52	Clay	52B	13.5	8.8-18.2
53	Mississippi	53A	0.5	0.0-1.5
		53B	1.0	0.0-2.4
		53C	7.5	3.9-11.2
		53D	18.0	12.7-23.3
		53E	2.0	3.9-11.2
54	Randolph	54A	6.5	3.1-10.0
		54B	5.5	2.3-8.7
55	Randolph	55A	26.5	20.4-32.6
		55B	10.0	5.8-14.2
		55C	6.0	2.7-9.3

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.
[b] Confidence intervals show the % survival range for a single progeny.

Table 1.2 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
56	Randolph	56A	22.5	16.7-28.3
		56B	8.5	4.6-12.4
		56C	17.0	11.8-22.2
57	Jefferson	57A	6.0	2.7-9.3
58				
59	Jefferson	59A	2.5	0.3-4.7
60	Jefferson	60A	6.0	2.7-9.3
		60D	7.0	3.5-10.5
61	Jefferson	61A	-[1]	-
		61B	-	-
		61C	-	-
62	Jefferson	62A	-	-
63	Jefferson	63A	3.5	1.0-6.1
64	Jefferson	64A	3.5	1.0-6.1
65	Jefferson	65A	3.5	1.0-6.1
66	Jefferson	66A	18.0	12.7-23.3
67	Jackson	67A	8.0	4.2-11.8
		67B	1.5	0.0-3.2
		67C	1.5	0.0-3.2
		67D	2.5	0.3-4.7
		67E	3.5	1.0-6.1
68	Jackson	68A	1.5	0.0-3.2
		68B	3.0	0.6-5.4
		68C	4.5	1.6-7.4
		68D	1.5	0.0-3.2
		68E	0.5	0.0-1.5
69	Jackson	69A	7.5	3.9-11.2
		69B	9.0	5.0-13.0
		69C	8.0	4.2-11.8
		69D	11.5	7.1-15.9
		69E	4.5	1.6-7.4

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.
[b] Confidence intervals show the % survival range for a single progeny.

[1] Palmer amaranth seed not viable in this accession

Table 1.2 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) progeny collected from each plant resistant to 0.86 kg ae/ha of glyphosate. [a]

Accession	County	Plant	% Survival	95% C I [b]
70	Jackson	70A	9.0	5.0-13.0
		70B	5.5	2.3-8.7
		70C	5.5	2.3-8.7
		70E	3.5	1.0-6.1
71	Jackson	71A	8.0	4.2-11.8
		71B	79.0	73.4-84.7
		71C	5.5	2.3-8.7
		71E	36.5	29.8-43.2
72	Crittenden	72A	2.5	0.3-4.7
		72B	10.0	5.8-14.2
		72C	8.5	4.6-12.4
		72D	18.5	13.1-23.9
		72E	31.0	24.6-37.4
73	Crittenden	73A	28.0	21.8-34.2
		73B	41.5	34.7-48.3
		73C	19.5	14.0-25.0
		73D	12.5	7.9-17.1
		73E	30.0	23.7-36.5
74	Crittenden	74A	5.0	2.0-8.0
		74B	9.0	5.0-13.0
		74C	4.5	1.6-7.4
		74D	32.5	26.0-39.0
		74E	15.0	10.1-20.0

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.

[b] Confidence intervals show the % survival range for a single progeny.

Table 1.3 The percent of Palmer amaranth (*Amaranthus palmeri*) accession (2007) resistant to 0.86 kg ae/ha of glyphosate. [a]

County	% Survival	95% C I [b]
Clay	1.0	0.0-2.4
Clay	7.0	3.5-10.5
Clay	13.5	8.8-18.2
Craighead	4.1	2.9-5.3
Craighead	6.7	5.2-8.3
Craighead	13.9	11.9-16.0
Craighead	15.7	13.3-18.1
Craighead	17.7	15.2-20.3
Crittenden	13.2	11.1-15.3
Crittenden	14.1	11.9-16.3
Crittenden	26.3	23.6-29.0
Greene	0.2	0.0-1.83
Greene	2.5	0.3-4.7
Greene	-[1]	-
Greene	-	-
Greene	-	-
Greene	-	-
Jackson	2.2	1.3-3.1
Jackson	3.4	2.3-4.5
Jackson	4.7	3.4-6.0
Jackson	8.1	6.4-9.8
Jackson	32.3	29.0-35.5

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.

[b] Confidence intervals show the weighted mean % survival range of plants from a single accession.

[1] Palmer amaranth seed not viable in this accession

Table 1.3 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) accession (2007) resistant to 0.86 kg ae/ha of glyphosate. [a]

County	% Survival	95% C I [b]
Jefferson	2.5	0.3-4.7
Jefferson	3.5	1.0-6.1
Jefferson	3.5	1.0-6.1
Jefferson	3.5	1.0-6.1
Jefferson	6.0	2.7-9.3
Jefferson	6.5	4.1-8.9
Jefferson	18.0	12.7-23.3
Jefferson	-[1]	-
Jefferson	-	-
Jefferson	-	-
Lawrence	9.4	7.1-11.7
Lawrence	10.5	8.2-12.9
Lawrence	12.2	9.6-14.7
Lawrence	16.4	13.5-19.3
Lawrence	24.0	20.0-28.0
Lee	23.8	20.2-27.5
Lee	41.0	38.0-44.1
Lee	69.4	66.2-72.6
Lee	83.0	80.4-85.6

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.

[b] Confidence intervals show the weighted mean % survival range of plants from a single accession.

[1] Palmer amaranth seed not viable in this accession

Table 1.3 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) accession (2007) resistant to 0.86 kg ae/ha of glyphosate. [a]

County	% Survival	95% C I [b]
Mississippi	0.2	0.0-0.5
Mississippi	0.3	0.0-0.6
Mississippi	0.7	0.2-1.2
Mississippi	0.9	0.3-1.5
Mississippi	0.9	0.3-1.5
Mississippi	1.1	0.5-1.8
Mississippi	1.4	0.7-2.1
Mississippi	1.8	1.0-2.6
Mississippi	3.9	2.7-5.1
Mississippi	5.8	4.4-7.3
Mississippi	6.8	5.2-8.4
Phillips	7.3	5.7-8.9
Phillips	11.7	9.7-13.7
Phillips	16.8	14.6-19.1
Phillips	20.1	17.6-22.6
Phillips	22.3	19.7-25.0
Phillips	29.1	26.0-32.2
Poinsett	5.8	4.4-7.2
Poinsett	11.4	9.5-13.4
Poinsett	14.7	12.5-16.8
Poinsett	16.7	14.5-19.0
Poinsett	21.8	19.3-24.3
Poinsett	36.7	33.8-39.6

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.

[b] Confidence intervals show the weighted mean % survival range of plants from a single accession.

Table 1.3 cont. The percent of Palmer amaranth (*Amaranthus palmeri*) accession (2007) resistant to 0.86 kg ae/ha of glyphosate. [a]

County	% Survival	95% C I [b]
Randolph	6.0	3.7-8.3
Randolph	14.2	11.4-17.0
Randolph	16.0	13.1-18.9
St. Francis	8.0	6.0-10.0
St. Francis	25.6	22.5-28.8
St. Francis	29.3	26.0-32.7
St. Francis	32.3	28.2-36.3
St. Francis	85.1	81.6-88.5
White	0.4	0.0-0.8
White	0.5	0.0-0.2

[a] Abbreviations: kg; kilogram; ae, acid equivalent; ha, hectare; CI, confidence interval.
[b] Confidence intervals show the weighted mean % survival range of plants from a single accession.

Chapter 2

Palmer Amaranth (*Amaranthus palmeri*) Control with Fomesafen and Glufosinate in Cotton (*Gossypium hirsutum*)

Palmer Amaranth (*Amaranthus palmeri*) Control with Fomesafen and Glufosinate in Cotton (*Gossypium hirsutum*)

Palmer amaranth is prone to the evolution of herbicide resistance, with confirmed resistance to four herbicide modes of action in the United States. Traditionally, herbicidal control of Palmer amaranth in cotton was attained by implementing a program approach. The traditional approach was slowly replaced with glyphosate-only postemergence over-the-top applications, after the introduction of glyphosate-resistant cotton cultivars in 1997. Three field studies were conducted at Rohwer, Arkansas and Keiser, Arkansas in 2006 and 2007. The objectives were to 1) determine effective rates and timings of fomesafen, residual PRE's, and glufosinate for control of Palmer amaranth in cotton and 2) identify injury to cotton, if any, caused by fomesafen applied preplant or preemergence. At Rohwer 7 DAE fomesafen at 0.21 kg ai/ha and flumioxazin at 0.071 kg ai/ha applied at 0 DPP caused stand count reduction of 5 and 11 plants (26 and 58%) /1.5 m of row respectively, when averaged across years. No stand reduction occurred at Keiser. Fluometuron at 1.12 kg ai/ha applied at 0 DPP was the only treatment that controlled Palmer amaranth less than 90% 7 DAE. Fomesafen at 0.28 kg ai/ha, fluometuron at 1.12 kg ai/ha, flumioxazin at 0.036 kg ai/ha, diuron at 0.56 kg ai/ha, and pendimethalin at 1.12 kg ai/ha applied PRE followed by three applications of glufosinate at 0.71 kg ai/ha applied to 5 cm tall Palmer amaranth resulted in 90 to 93% control. Glufosinate at 0.57 kg ai/ha applied at 2- to 3-, 6- to 8-, and 12-leaf cotton followed by fomesafen at 0.28 kg ai/ha applied at layby was the only treatment that did not provide season-long control (below 90%) of Palmer amaranth.

Nomenclature: Glyphosate; Palmer amaranth, *Amaranthus palmeri* S. Wats.; cotton, *Gossypium hirsutum* L.

Key words: Glyphosate-resistant, Palmer amaranth.

Introduction

Palmer amaranth is native to the Americas (Bridges 1992; Holm et al. 1977; Sauer 1967; Sweat et al. 1998) and shows rapid growth initially (Sellers et al. 2003). Palmer amaranth has a terminal spike inflorescence with male and female flowers on separate plants (dioecious) (Elmore1990; Keeley et al. 1987). Palmer amaranth has an extended emergence period that coincides with crop emergence and establishment, aggressive growth at high temperatures, prolific seed production (up to 600,000 seeds per female plant), high water use efficiency, and C_4 photosynthetic mechanism (Guo and Al-Khatib 2003; Horak and Loughlin 2000; Jha et al. 2007; Jha and Norsworthy 2009; Keeley et al. 1987; Massinga et al. 2003; Sellers et al. 2003; Uva et al. 1997; Weaver 1984). Palmer amaranth is prone to developing herbicide resistance, with confirmed resistance to four herbicide modes of action in the United States (Heap 2012).

Traditionally, herbicidal control of Palmer amaranth in cotton was attained by implementing a program approach. These traditional programs included a soil-applied preplant incorporated and/or preemergence (PRE) herbicide followed by a selective herbicide applied postemergence (POST) over-the-top or a post-directed herbicide early POST followed by a post-directed herbicide late POST and concluded with a post-directed layby treatment (Faircloth et al. 2001; Jordan et al. 1997; Snipes et al. 1984). With the introduction of glyphosate-resistant cotton cultivars in 1997, the traditional approach was slowly replaced with glyphosate POST over-the-top applications (Faircloth et al. 2001; Givens et al. 2009; Jones and Snipes 1999; Patterson et al. 1998; Young 2006). In many cases, glyphosate-only programs were adopted due to effectiveness and ease of use.

As early as 1999 researchers were reporting that glyphosate-only weed control programs could present economic risks to cotton producers (Askew and Wilcut 1999; Faircloth et al. 2001), especially in the presence of glyphosate-resistant weeds. Glyphosate tank mixed with residual herbicides has provided excellent weed control and high yields in cotton (Faircloth et al. 2001; Isgett et al. 1997; Keeton and Murdock 1997). However, this tank-mix is not an effective tool for resistance management if the Palmer amaranth has already emerged. The continued use of glyphosate-based programs resulted in the evolution of glyphosate-resistant Palmer amaranth in Arkansas, Georgia, Tennessee, North Carolina, and South Carolina from 2004 to 2007 (Culpeper et al. 2006; Scott et al. 2007; York et al. 2007).

In 2005, a single Palmer amaranth population in Arkansas survived at least two applications of glyphosate at 0.86 kg ae/ha (Norsworthy et al. 2008; Scott et al. 2007; Scott and Smith 2006). By 2009, 23 counties in Arkansas were known to be infested with glyphosate-resistant Palmer amaranth (Meier et al. 2009). Glyphosate-resistant Palmer amaranth has forced cotton producers to rely less and less on glyphosate alone and to use other methods of control.

Fomesafen is a diphenylether herbicide. Diphenylether herbicides are fast-acting, contact, photobleaching herbicides that cause phytotoxic effects by inhibiting protoporphyrinogen oxidase, which results in concentration of protoporphyrin IX, a potent photosensitizer (Duke et al. 1989). Fomesafen is a widely used herbicide that is labeled for POST over-the-top applications in soybean [*Glycine max* (L.) Merr.] (Vencill 2002). Previous research shows that PRE-applied fomesafen controls Palmer amaranth greater than 90% in cotton (Lunsford et al. 1998). Murdock and Keeton (1998) reported that only six experiments had been reported in the 1990s to evaluate fomesafen in cotton, although many more have now been conducted. Research has indicated that cotton has tolerance to fomesafen applied PRE at 0.28 and 0.42 kg ai/ha

(Baumann et al. 1998; Lunsford et al. 1998; Stephenson et al. 2004). Baumann et al. (1998) reported that PRE-applied fomesafen resulted in <10% injury to the cotton and did not negatively affect yield. Stephenson et al. (2004) reported that PRE-applied fomesafen provided seedcotton yield equal to a weed-free check. Smith et al. (2005) reported that PRE-applied fomesafen provided higher seedcotton yield and Palmer amaranth control than all other standard PRE herbicides.

Dinitroaniline- and sulfonylurea-resistant Palmer amaranth (Gossett et al. 1992; Sprague et al. 1997), as well as the lack of control provided by many POST herbicides, is a major problem in cotton production. Standard PRE herbicides such as fluometuron, prometryn, diuron, and pendimethalin can control up to 88% of Palmer amaranth while fomesafen often provides up to 99% control (Smith et al. 2005). The need for a herbicide or herbicide program that will provide consistent control of Palmer amaranth in cotton is imperative. Fomesafen provides cotton growers with an alternate mode of action for controlling dinitroaniline-, sulfonylurea-, and glyphosate-resistant and nonresistant biotypes of Palmer amaranth and aids in resistance management in cotton (Retzinger and Mallory-Smith 1997; Troxler et al. 2002).

Glufosinate-resistant (Liberty Link) cotton was commercially released in 2004 (Anonymous 2006). Its popularity has grown due to herbicide resistance and improved varieties for the Midsouth. Glufosinate-resistant cotton contains a gene from *Streptomyces viridochromogenes* that encodes for phosphinothricin acetyltransferase, an enzyme that catalyzes the conversion of lethal L-phosphinothricin into nonlethal *N*-acetyl-L- phosphinothricin (Devine et al.1993; Gardner et al. 2006; Hinchee et al. 1993). Glufosinate was originally created for use in orchards and as a pre- harvest desiccant (Duke and Lydon 1987; Kishore and Shah 1988; Ratnayake and Shaw 1992; Ritter and Menbere 2001). Glufosinate inhibits glutamine synthetase, which leads to rapid accumulation of ammonia within the plant (Coetzer and Al-Khatib 2001). Subsequent damage to chloroplast and eventual termination of photosynthesis results in necrosis of plant tissue and death of the plant (Devine et al. 1993; Everman et al. 2009; Lacuesta et al. 1992; Pline et al. 1999; Wendler et al. 1990).

Glufosinate use in glufosinate-resistant cotton has provided growers with a new effective POST weed control option. Glufosinate is a nonselective herbicide that requires thorough spray coverage to ensure good broadleaf weed control (Corbett et al. 2004; Everman et al. 2009; Steckel et al. 1997a). Although glufosinate is considered non-selective, weed sensitivity varies greatly (Ridley and McNally 1985; Steckel at al. 1997a). Environmental conditions and application rate also influence glufosinate efficacy (Steckel et al. 1997a; Van Wychen et al. 1999). Glufosinate acts faster than glyphosate (Anonymous 1996; Bellinder et al. 1987; Tachibana and Kaneko 1986; Wilson et al. 1985), and visible symptoms are usually evident within 10 h to 7 d after application. The efficacy of glufosinate is influenced by absorption and translocation (Steckel et al. 1997b).

Until 2007, glyphosate was providing effective control of Palmer amaranth. However, since the confirmation of glyphosate-resistant Palmer amaranth (Norsworthy et al. 2008; Scott et al. 2007; Scott and Smith 2006), growers have needed a new option. Palmer amaranth 2 to 5 cm tall was controlled >96% with a single application glufosinate, while sequential applications provided 100% control of 8- to 10-cm tall Palmer amaranth (Corbett et al. 2004). Steckel et al. (2006) also found that higher rates of glufosinate prevented or delayed regrowth of glyphosate-resistant horseweed (*Conyza canadensis* L. Cronq.).

The objectives of this research were to 1) determine effective rates and timings of fomesafen, and glufosinate for control of Palmer amaranth in cotton and 2) identify injury to cotton, if any, caused by fomesafen and other residual herbicides applied preplant or preemergence.

Materials and Methods

General. Field studies were conducted at Rohwer and Keiser, AR. Soil at Rohwer was a Hebert silt loam (fine-silty, mixed, active, thermic Aeric Epiaqualfs; 16% sand, 67% silt, 17% clay) with a pH of 7.1 and 2.2% organic matter and soil at Keiser was a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts; 3.5% sand, 37.4% silt, 59.1% clay) with pH of 7.3 and 1% organic matter. Both sites were fertilized according to University of Arkansas soil test recommendations for cotton cropping systems in each year. The experimental sites were prepared by disking, field cultivating, and hipping into 1-m-wide rows with a roller hipper.

The Rohwer site was sprinkler irrigated throughout the growing season in each year by a lateral-move, over-head sprinkler. The Keiser site was irrigated by furrow irrigation. All PRE and preplant PPL applications received rainfall or were irrigated 3 to 5 days after application to ensure proper activation. Following activation, irrigation was triggered when water deficits reached approximately 25 mm. The water deficit was calculated by the University of Arkansas irrigation scheduler computer system[1]. The experimental design for the studies was a randomized complete block with four replications. Plots were over-seeded with Palmer amaranth, acquired from Azlin Seed[2], after cotton was planted to ensure a uniform Palmer amaranth population. Applications were made using a CO_2-pressurized backpack sprayer equipped with flat fan nozzles[3] delivering 112 L/ha at 310 kPa. At the time of herbicide application, soil and environmental conditions were recorded. Also recorded were soil and environmental conditions at planting and emergence dates for cotton (data not shown). Daily temperatures and rainfall were obtained from weather stations located at Rohwer and Keiser (data not shown).

Visual ratings were based on a scale of 0 to 100%, with 0% equal to no Palmer amaranth control or cotton injury and 100% equal to complete control of Palmer amaranth or death of cotton plants. The center two rows of each four-row plot were harvested for yield by a cotton picker modified for small-plot harvest. All treated plots were rated as compared to an untreated check plot. Data were analyzed ANOVA at $p = 0.05$ using SAS.

Field Study 1. A study was conducted at the University of Arkansas Southeast Research and Extension Center in Rohwer, AR, and the University of Arkansas Northeast Research and Extension Center in Keiser, AR, in 2006 and 2007 to determine most effective rate (0.21 or 0.28 kg ai/ha) and timings of fomesafen and other residual herbicides for the control of Palmer amaranth in Roundup Ready (RR) cotton and identify injury to cotton, if any, caused by fomesafen and other herbicides applied PRE (Table 2.1).

Herbicides used were fomesafen[4], flumioxazin[5], fluometuron[6], prometryn[7], diuron[8], and pendimethalin[9]. Herbicide treatments were applied at four preplant timings (21, 14, 7, and 0 days), and an untreated check was included for comparison. All plots were maintained weed-free by applying 0.86 kg ae/ha of glyphosate[10] at 8- and 12-leaf cotton followed by a layby application of flumioxazin applied late-season. Roundup Ready Flex cotton[11] was planted at 136,000 seeds/ha in four-row plots, with rows being 1 m apart and 8.5 m in length.

The number of cotton plants per 1.5 m of row and visible cotton injury ratings (chlorosis, necrosis, and stunting) were recorded 1, 2, and 3 weeks after emergence (WAE). Visible ratings for Palmer amaranth control were taken at 7, 14, and 21 days after emergence.

Field Study 2. A study was conducted at the University of Arkansas Southeast Research and Extension Center in Rohwer, AR, and the University of Arkansas Northeast Research and Extension Center in Keiser, AR, in 2006 and 2007 to determine effective rates and application timings of glufosinate for control of Palmer amaranth in Liberty Link (LL) cotton, and to determine effectiveness of fomesafen and other PRE applied cotton herbicides in LL. PRE herbicides followed by glufosinate[12] at various rates and timings were evaluated in the LL cotton system (Table 2.2). Herbicides used were glufosinate at 0.51 and 0.71 kg ai/ha applied to 5- and 10-cm tall Palmer amaranth, *S*-metolachlor[13] at 1.06 kg ai/ha applied to 5- and 10-cm tall Palmer amaranth, fomesafen at 0.21 and 0.28 kg ai/ha, fluometuron, prometryn, and pendimethalin at 1.12 kg ai/ha, flumioxazin at 0.036 kg ai/ha, and diuron at 0.56 kg ai/ha applied PRE. Liberty Link cotton was planted at 136,000 seeds/ha in four-row plots, with rows being 1 m apart and 8.5 m in length. Palmer amaranth was assessed at 14 and 35 days after cotton emergence and at pre-harvest.

Field Study 3. A study was conducted at the University of Arkansas Southeast Research and Extension Center in Rohwer, AR, in 2006 and 2007 to evaluate effectiveness of glufosinate and glufosinate tank-mixtures with fomesafen in a weed control system for Palmer amaranth control in Liberty Link cotton. Herbicide programs that included PRE herbicides were diuron or fluometuron at 1.12 kg ai/ha, or fomesafen at 0.21kg ai/ha PRE followed by glufosinate at 0.57 kg ai/ha or glufosinate at 0.57 kg ai/ha plus metolachlor at 1.06 kg ai/ha applied at 4-leaf cotton followed by glufosinate at 0.57 kg ai/ha, fomesafen at 0.21 kg ai/ha plus non-ionic surfactant at

0.25%v/v, prometryn plus trifloxysulfuron at 2.1 kg ai/ha, or MSMA at 2.26 kg ai/ha plus diuron at 0.56 kg ai/ha applied to 10-leaf cotton followed by glufosinate at 0.57 kg ai/ha plus flumioxazin at 0.054 kg ai/ha or fomesafen at 0.21 or 0.28 kg ai/ha applied at layby. Systems used in the absence of a PRE herbicide were glufosinate at 0.57 kg ai/ha applied sequentially at 2- to 3-, 6- to 8-, and 12-leaf cotton followed by flumioxazin at 0.054 kg ai/ha or fomesafen at 0.21 or 0.28 kg ai/ha applied at layby (Table 2.3). Liberty Link cotton was planted at 136,000 seeds/ha in four-row plots, with rows being 1 m apart and 8.5 m in length.

Results and Discussion

Field Study 1. A reduction in the number of cotton plants per m of row is a good indicator of crop injury. At Rohwer 7 DAE fomesafen at 0.21 kg ai/ha and flumioxazin at 0.071 kg ai/ha applied at 0 DPP caused stand count reduction of 26 and 58% respectively, when averaged across years. When applied at 7, 14, or 21 DPP no reduction was observed. No reduction in stand count was noted with fluometuron, prometryn, diuron, or pendimethalin at any timing. At Keiser 7 DAE, no reduction in stand count was noted with any herbicide or timing when averaged across years (Table 2.4). An untimely rain fall event as cotton was emerging at Rohwer may have influenced stand count reductions.

Visually assessed stunting of 6% or greater was noted with 5 of the 28 PPL treatments when averaged across year and location at 21 DAE. Fomesafen at 0.21 and 0.28 kg ai/ha, flumioxazin at 0.071 kg ai/ha, prometryn at 1.12 kg ai/ha, and pendimethalin at 1.12 kg ai/ha caused stunting of 15, 12, 48, 6, and 13%, respectively. Fluometuron at 1.12 kg ai/ha and diuron at 0.56 kg ai/ha caused 0 and 2% visible stunting when applied 0 DPP. At the 7 DPP timing, fomesafen at 0.28 kg ai/ha, flumioxazin at 0.071 kg ai/ha, and pendimethalin at 1.12 kg ai/ha caused 4% or less stunting. The 14 DPP treatments of fomesafen at 0.21 kg ai/ha, flumioxazin at 0.071 kg ai/ha, and fluometuron at 1.12 kg ai/ha caused less than 4% cotton stunting. Fomesafen at 0.21 kg ai/ha, flumioxazin at 0.071 kg ai/ha, and pendimethalin at 1.12 kg ai/ha applied 21 DPP caused less than 3% stunting at 21 DAE (Table 2.5). Injury of less than 5% did not likely have any adverse effects on the development of the cotton crop and did not affect cotton yield (Table 2.7).

Palmer amaranth control must be obtained early in cotton (Smith et al. 2005). The best way to ensure control is by using a preplant or preemergence herbicide (Faircloth et al. 2001; Jordan et al. 1997; Snipes et al. 1984). Palmer amaranth control was averaged across locations and years. At 7 DAE of the cotton, fomesafen applied at 0.21 and 0.28 kg ai/ha, flumioxazin at 0.071 kg ai/ha, prometryn at 1.12 kg ai/ha, diuron at 0.56 kg ai/ha, and pendimethalin at 1.12 kg ai/ha applied at 21, 14, 7, and 0 DPP all controlled Palmer amaranth 90 to 100%. Fluometuron at 1.12 kg ai/ha applied at 21, 14, and 7 DPP provided palmer control of 90 to 97%. Fluometuron at 1.12 kg ai/ha applied at 0 DPP was the only treatment 7 DAE that provided less than 90%. At 14 DAE fomesafen applied at 0.21 kg ai/ha 7 and 21 DPP, fomesafen applied at 0.28 kg ai/ha 7 DPP, flumioxazin at 0.071 kg ai/ha 7, 14, and 21 DPP and diuron at 0.56 kg ai/ha 14 and 21 DPP controlled Palmer amaranth 95 to 98%. Palmer amaranth control of 90 to 94% 21 DAE was provided by fomesafen applied at 0.21 kg ai/ha 7 DPP and flumioxazin at 0.071 kg ai/ha 7 and 14DPP (Table2.6). Because most treatments provided the same or very similar levels of control and injury ratings, there was little to no variation in these data across replication, year or location; hence, analysis by ANOVA was deemed invalid. Means tables (Tables 2.5, 2.6, 2.8, and 2.10) are shown.

Many parameters can be used to determine injury to a cotton crop. One of the most important and sensitive parameters is cotton yield. Seedcotton yield was combined across herbicide treatment, location, and years, because a timing main effect was the only significant effect identified. Seedcotton yield for the 0 DPP timing was 290 to 380 kg/ha lower than the 21, 14, or 7 DPP timings, which were not significantly different (Table 2.7). The yield reduction is likely influenced by the cotton injury that was recorded as stand reduction (Table 2. 4) and visible stunting (Table 2. 5). However, Palmer amaranth control was similar when fomesafen was applied either 0, 7, or 14 days prior to planting (Table 2.6). Therefore, the more injurious timing (0DPP) was not needed in order to maintain control out to 21 DAE. This data suggest that fomesafen could safely be applied to cotton up to 7 DPP. Further research is needed to determine the impact that rainfall, soil type and other factors might have on this plant back interval.

Field Study 2. Fomesafen at 0.28 kg ai/ha, fluometuron at 1.12 kg ai/ha, flumioxazin at 0.036 kg ai/ha, diuron at 0.56 kg ai/ha, and pendimethalin at 1.12 kg ai/ha applied PRE followed by three applications of glufosinate at 0.71 kg ai/ha applied to 5-cm tall Palmer amaranth provided 90 to 93% control. Glufosinate at 0.71 kg ai/ha applied at 5 cm in three consecutive applications also provided 93% control of Palmer amaranth. Eleven glufosinate-based herbicide systems were used in field study 2. Six of the 7 systems that included a PRE followed by glufosinate provided season-long Palmer amaranth control (90 to 93%), regardless of which residual herbicide was used when averaged over location and year. Glufosinate alone also controlled Palmer amaranth 93% pre-harvest when applied three times at 0.71 kg ai/ha versus 89% control with 0.57 kg ai/ha. In addition, glufosinate applied at 5 cm (0.71 kg ai/ha) followed by a single application at 10 cm (1.06 kg ai/ha) controlled Palmer amaranth only 80% (Table 2.8). Most treatments provided similar levels of Palmer amaranth control and there was little variation in these data across replication, year, or location; hence, analysis by ANOVA was deemed invalid (Table 2.8).

Control of Palmer amaranth with glufosinate is directly influenced by plant size, which indicates complete coverage of the plant and early season application is a necessity (Corbett et al. 2004; Coetzer et al. 2002; Steckel et al. 1997a; Steckel et al. 1997b). When controlling Palmer amaranth POST over-the-top with glufosinate, smaller weed size is better. Previously, multiple glufosinate applications spaced 10-14 days apart ensured complete control of Palmer amaranth (Corbett et al. 2004). In addition to timing, these data indicate that a residual herbicide applied at or prior to planting is effective in a glufosinate based program in LL cotton. Although 3 applications of glufosinate did provide 93% control of Palmer amaranth when evaluated at harvest, this program does nothing to aid in resistance management. The use of a residual herbicide in this system could help prevent the occurrence of glufosinate-resistant Palmer amaranth.

Seedcotton yield was not significantly different among all 11 treatments in field study 2 (Table 2.9). The highest numerical yields were provided by prometryn or pendimethalin at 1.12 kg ai/ha PRE followed by three consecutive applications of glufosinate at 0.71 kg ai/ha applied to 5 cm Palmer amaranth and three consecutive applications of glufosinate at 0.71 kg ai/ha applied to 5 cm Palmer amaranth which yielded 2620, 2590, and 2550 kg/ha of seedcotton respectively. Overall yields ranged from 2030 to 2620 kg/ha.

Even though yields did not vary with the addition of PRE applied herbicides in this trial an added benefit of using these herbicides in glufosinate tolerant cotton would be resistance management. Also, the use of PRE herbicides in otherwise total post systems can allow for flexibility in making POST applications in a timely manner. When used in combination with residual herbicides, at the proper rate and timing, glufosinate can provide good Palmer amaranth control and seedcotton yield.

Field Study 3. Previous research has shown that the best way to ensure total weed control in cotton is to use a complete herbicide program (Faircloth et al. 2001; Jordan et al. 1997; Snipes et al. 1984). Field study 3 contained 16 herbicide systems with 15 providing 91 to 100% control of Palmer amaranth when evaluated at harvest (Table 2.10). Herbicide programs that included preemergence herbicides were diuron or fluometuron at 1.12 kg ai/ha, or fomesafen at 0.21kg ai/ha PRE followed by glufosinate at 0.57 kg ai/ha or glufosinate at 0.57 kg ai/ha plus S-metolachlor at 1.06 kg ai/ha applied at 4-leaf cotton followed by glufosinate at 0.57 kg ai/ha, fomesafen at 0.21 kg ai/ha plus non-ionic surfactant at 0.25%v/v, prometryn plus trifloxysulfuron at 2.1 kg ai/ha, or MSMA at 2.26 kg ai/ha plus diuron at 0.56 kg ai/ha applied to 10-leaf cotton followed by glufosinate at 0.57 kg ai/ha plus flumioxazin at 0.054 kg ai/ha or fomesafen at 0.21 or 0.28 kg ai/ha applied at layby. Systems used in the absence of a PRE were glufosinate at 0.57 kg ai/ha applied sequentially at 2- to 3-, 6- to 8-, and 12-leaf cotton followed by flumioxazin at 0.054 kg ai/ha or fomesafen at 0.21 or 0.28 kg ai/ha applied at layby**.** Glufosinate at 0.57 kg ai/ha applied at 2- to 3-, 6- to 8-, and 12-leaf cotton followed by fomesafen at 0.28 kg ai/ha applied at layby was the only system that did not provide season-long control (84%) of Palmer amaranth (Table 2.10). The failure of the glufosinate only program up to layby to provide season-long control illustrates the benefit of a residual program early in cotton for Palmer amaranth control. Glufosinate is a valuable tool for Palmer amaranth control in cotton, but should not be relied upon for total POST control.

Seedcotton yield was greatly influenced by the wide variety of herbicides and timings used in the herbicide systems in field study 3. Fluometuron at 1.12 kg ai/ha followed by glufosinate at 0.57 kg ai/ha plus metolachlor at 1.06 kg ai/ha applied at 4-leaf cotton followed by MSMA at 2.26 kg ai/ha plus diuron at 0.56 kg ai/ha applied to 10-leaf cotton followed by glufosinate at 0.57 kg ai/ha plus flumioxazin at 0.054 kg ai/ha at layby provided a yield of 2300 kg/ha of seedcotton when averaged across years (P=0.002). The treatment that provided the least seedcotton yield was glufosinate at 0.57 kg ai/ha applied at 2- to 3-, 6- to 8-, and 12-leaf cotton followed by fomesafen at 0.28 kg ai/ha, which provided 1190 kg/ha (Table 2.11). Low yield has been reported as a deterrent for growing Liberty Link cotton (Culpepper et al. 2009). Field study 3 proves that with proper Palmer amaranth control glufosinate-resistant cotton can provide high seedcotton yields.

Summary of Field Studies. These field studies were established to provide cotton producers control options for glyphosate-resistant Palmer amaranth. Because of this, most of the herbicide systems used were designed to provide season-long Palmer amaranth control, which resulted in very low variance across years and locations for some data parameters, such as percent weed control and visible rating of stunting. However, these data were instrumental in providing herbicide recommendations for the cotton producers of Arkansas and were used in the development of recommendations in the Extension publication MP-44. The data obtained from study 1 provided critical information which supported the first 24c label for fomesafen (Reflex) use in Arkansas cotton. These data supported the preplant timing being adjusted from 21 DPP to 14 DPP and led to further refinements in this recommendation based on rainfall and soil type. The data obtained from field studies 2 and 3 supported recommendations for applying glufosinate at 0.57 and 0.71 kg ai/ha to 5 cm Palmer amaranth or smaller. These data also supported the addition of residual herbicides (PRE and POST) into Palmer amaranth control programs in Liberty Link cotton.

Sources of Material

[1]Irrigation Scheduler, University of Arkansas • Division of Agriculture Cooperative Extension Service 2301 South University Avenue Little Rock, Arkansas 72204 • USA

[2] Azlin Seed, Azlin Seed Service 112 Lilac Drive Leland, MS 38756-3012

[3] GreenLeaf Airmix 11015 flat-fan spry tips, GreenLeaf Technologies P.O. Box 1767, Covington, LA, 70434.

[4] Fomesafen, Reflex®, Syngenta Crop Protection, Inc. Greensboro, North Carolina 27409

[5] Flumioxazin, Valor ™ SX, Valent U.S.A. Corporation, P. O. Box 8025, Walnut Creek, CA 94596.

[6]Fluometuron, Cotoran® 4L, Makhteshim Agan of North America, Inc. 4515 Falls of Neuse Road Suite 300 Raleigh, NC 27609

[7]Prometryn, Caparol®, Syngenta Crop Protection, Inc. P. O. Box 18300 Greensboro, North Carolina 27419-8300

[8]Diuron, Direx®, E. I. du Pont de Nemours and Company, Wilmington, Delaware 19898

[9]Pendimethalin, Prowl® H_2O, BASF Corporation 26 Davis Dr. Research Triangle Park, NC 27709

[10] Glyphosate herbicide, Monsanto Co. 800 North Lindberg Blvd., St. Louis MO 63167.

[11] Deltapine RRF cotton, Delta and Pine Land Seed Company LLC, One Cotton Row Scott, MS 38772 United States

[12]Glufosinate, Ignite® 280, Bayer Crop Science LP P. O. Box 12014, 2 TW Alexander Dr. Research Triangle Park, NC 27709

[13]S-Metolachlor, Dual Magnum®, Syngenta Crop Protection, Inc. Greensboro, North Carolina 27409

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Table 2.1 Treatment list for field study 1. [a]

Treatment number	Herbicide	Rate	Application timing
		kg ai/ha	
1	UTC		
2	Fomesafen	0.21	21 DPP
3	Fomesafen	0.21	14 DPP
4	Fomesafen	0.21	7 DPP
5	Fomesafen	0.21	0 DPP
6	Fomesafen	0.28	21 DPP
7	Fomesafen	0.28	14 DPP
8	Fomesafen	0.28	7 DPP
9	Fomesafen	0.28	0 DPP
10	Flumioxazin	0.07	21 DPP
11	Flumioxazin	0.07	14 DPP
12	Flumioxazin	0.07	7 DPP
13	Flumioxazin	0.07	0 DPP
14	Fluometuron	1.12	21 DPP
15	Fluometuron	1.12	14 DPP
16	Fluometuron	1.12	7 DPP
17	Fluometuron	1.12	0 DPP
18	Prometryn	1.12	21 DPP
19	Prometryn	1.12	14 DPP
20	Prometryn	1.12	7 DPP
21	Prometryn	1.12	0 DPP
22	Diuron	0.56	21 DPP
23	Diuron	0.56	14 DPP
24	Diuron	0.56	7 DPP
25	Diuron	0.56	0 DPP
26	Pendimethalin	1.12	21 DPP
27	Pendimethalin	1.12	14 DPP
28	Pendimethalin	1.12	7 DPP
29	Pendimethalin	1.12	0 DPP

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; DPP, days preplant; UTC, untreated check.

Table 2.2 Treatment list for field study 2. [a]

Treatment number	Herbicide	Rate	Palmer amaranth Application timing
		kg ai/ha	
1	UTC		
2	Glufosinate	0.57	5 cm
	Glufosinate	0.57	5 cm
	Glufosinate	0.57	5 cm
3	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
4	Glufosinate	0.71	5 cm
	Glufosinate	1.06	10 cm
5	Glufosinate	0.71	5 cm
	S-metolachlor	1.06	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
6	Fomesafen	0.21	PRE
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
7	Fomesafen	0.28	PRE
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
8	Fluometuron	1.12	PRE
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
9	Prometryn	1.12	PRE
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; cm, centimeter; PRE, preemergence.

Table 2.2 cont. Treatment list for field study 2. [a]

Treatment number	Herbicide	Rate	Palmer amaranth Application timing
		kg ai/ha	
10	Flumioxazin	0.036	PRE
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
11	Diuron	0.56	PRE
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
12	Pendimethalin	1.12	PRE
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm
	Glufosinate	0.71	5 cm

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; cm, centimeter; PRE, preemergence.

Table 2.3 Treatment list for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing
		kg ai/ha	
1	UTC		
2	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
3	Fomesafen	0.21	PRE
	Glufosinate	0.57	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
4	Diuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
5	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
6	Diuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence.

Table 2.3 cont. Treatment list for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing
		kg ai/ha	
7	Fomesafen	0.21	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
8	Glufosinate	0.57	2-3 lf cotton
	Glufosinate	0.57	6-8 lf cotton
	Glufosinate	0.57	12 lf cotton
	Flumioxazin	0.054	Layby
9	Glufosinate	0.57	2-3 lf cotton
	Glufosinate	0.57	6-8 lf cotton
	Glufosinate	0.57	12 lf cotton
	Fomesafen	0.21	Layby
10	Glufosinate	0.57	2-3 lf cotton
	Glufosinate	0.57	6-8 lf cotton
	Glufosinate	0.57	12 lf cotton
	Fomesafen	0.28	Layby
11	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Fomesafen	0.28	Layby
12	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Glufosinate	0.57	10 lf cotton
	Glufosinate	0.57	Layby
	Fomesafen	0.21	Layby

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence.

Table 2.3 cont. Treatment list for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing
		kg ai/ha	
13	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Prometryn + Trifloxysulfuron	2.1	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
14	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Fomesafen	0.21	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
15	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	Fomesafen	0.28	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
16	Fluometuron	1.12	PRE
	Glufosinate	0.57	4 lf cotton
	S-metolachlor	1.06	4 lf cotton
	MSMA	2	10 lf cotton
	Diuron	0.56	10 lf cotton
	Glufosinate	0.57	Layby
	Flumioxazin	0.054	Layby
17	Glufosinate	0.57	2-3 lf cotton
	S-metolachlor	1.06	2-3 lf cotton
	Glufosinate	0.57	6-8 lf cotton
	Glufosinate	0.57	12 lf cotton
	Flumioxazin	0.054	Layby

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence.

Table 2.4 Field study 1 stand counts taken in 1.5 meters of row 7 days after cotton emergence from herbicides applied 0, 7, 14, and 21 days preplant at Rohwer and Keiser averaged across years. [a] (P = 0.0014)

		Rohwer				Keiser			
		Days Preplant							
Herbicide	Rate	21	14	7	0	21	14	7	0
	kg ai/ha								
Untreated Check		19				20			
Fomesafen	0.21	19	18	18	14	20	20	19	18
Fomesafen	0.28	18	19	18	17	20	20	20	19
Flumioxazin	0.071	17	18	19	8	20	20	19	19
Fluometuron	1.12	17	18	18	17	20	21	19	18
Prometryn	1.12	21	21	17	18	19	19	19	19
Diuron	0.56	17	19	19	20	19	19	19	20
Pendimethalin	1.12	19	18	18	17	20	19	19	19

LSD to compare means at the same location = 3.

LSD to compare means at different location = 3.

[a] Abbreviations: kg, kilogram; ai, active ingredient; ha, hectare.

Table 2.5 Field study 1 visible stunting 21days after cotton emergence from herbicides applied 0 to 21 days preplant at Rohwer and Keiser averaged across location and years. [a]

		Days Preplant			
Herbicide	Rate	21	14	7	0
	kg ai/ha	%			
Untreated		0			
Fomesafen	0.21	1	3	0	15
Fomesafen	0.28	0	0	3	12
Flumioxazin	0.071	1	1	4	48
Fluometuron	1.12	0	2	0	2
Prometryn	1.12	0	0	0	6
Diuron	0.56	0	0	0	0
Pendimethalin	1.12	2	0	1	13

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg; kilogram; ai, active ingredient; ha, hectare.

Table 2.6 Palmer amaranth control for field study 1 averaged across years and location. [a]

Treatment number	Herbicide	Rate	Application timing	7 DAE	14 DAE	21DAE
		kg ai/ha			%	
2	Fomesafen	0.21	21	99	96	84
3	Fomesafen	0.21	14	96	91	87
4	Fomesafen	0.21	7	99	98	92
5	Fomesafen	0.21	0	94	87	84
6	Fomesafen	0.28	21	98	94	82
7	Fomesafen	0.28	14	97	93	84
8	Fomesafen	0.28	7	100	95	89
9	Fomesafen	0.28	0	94	84	80
10	Flumioxazin	0.07	21	97	96	88
11	Flumioxazin	0.07	14	98	96	94
12	Flumioxazin	0.07	7	99	98	90
13	Flumioxazin	0.07	0	91	90	87
14	Fluometuron	1.12	21	97	89	75
15	Fluometuron	1.12	14	90	91	81
16	Fluometuron	1.12	7	95	89	78
17	Fluometuron	1.12	0	87	82	79
18	Prometryn	1.12	21	97	92	80
19	Prometryn	1.12	14	98	93	72
20	Prometryn	1.12	7	97	91	70
21	Prometryn	1.12	0	90	84	60
22	Diuron	0.56	21	98	96	85
23	Diuron	0.56	14	97	95	86
24	Diuron	0.56	7	94	90	84
25	Diuron	0.56	0	93	88	84
26	Pendimethalin	1.12	21	95	90	79
27	Pendimethalin	1.12	14	97	93	86
28	Pendimethalin	1.12	7	91	83	71
29	Pendimethalin	1.12	0	95	88	78

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; DAE, days after emergence.

Table 2.7 Field study 1 seedcotton yield averaged across treatment, locations, and years. [a] (P < 0.0001)

Application timing (days preplant)	Cotton Yield kg/ha
21	2940
14	2910
7	2850
0	2560

LSD to compare mean at 0 timing with a mean at any other timing = 150.

LSD to compare any pair of means neither of which are at timing 0 = 150.

[a] Abbreviations: kg, kilogram; ha, hectare.

Table 2.8 Field study 2 Palmer amaranth control averaged across locations and years. [a]

Treatment number	Herbicide	Rate	Palmer amaranth application timing	14 DAE	35 DAE	Pre-harvest
		kg ai/ha			%	
2	Glufosinate	0.57	5 cm	91	91	89
	Glufosinate	0.57	5 cm			
	Glufosinate	0.57	5 cm			
3	Glufosinate	0.71	5 cm	92	95	93
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
4	Glufosinate	0.71	5 cm	94	81	80
	Glufosinate	1.06	10 cm			
5	Glufosinate	0.71	5 cm	94	95	89
	S-metolachlor	1.06	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
6	Fomesafen	0.21	PRE	92	92	91
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
7	Fomesafen	0.28	PRE	91	93	93
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
8	Fluometuron	1.12	PRE	95	96	93
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
9	Prometryn	1.12	PRE	93	96	86
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; cm, centimeter; PRE, preemergence; DAE, days after emergence.

Table 2.8 cont. Field study 2 Palmer amaranth control averaged across locations and years. [a]

Treatment number	Herbicide	Rate	Palmer amaranth application timing	14 DAE	35 DAE	Pre-harvest
		kg ai/ha			%	
10	Flumioxazin	0.036	PRE	92	98	90
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
11	Diuron	0.56	PRE	93	97	92
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
12	Pendimethalin	1.12	PRE	94	97	91
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			
	Glufosinate	0.71	5 cm			

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; cm, centimeter; PRE, preemergence; DAE, days after emergence.

Table 2.9 Field study 2 seedcotton yield averaged across locations and years. [a] (P = 0.1272)

Treatment number	Herbicide	Rate	Palmer amaranth Application timing	Cotton Yield
		kg ai/ha		kg/ha
2	Glufosinate	0.57	5 cm	2340
	Glufosinate	0.57	5 cm	
	Glufosinate	0.57	5 cm	
3	Glufosinate	0.71	5 cm	2550
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
4	Glufosinate	0.71	5 cm	2030
	Glufosinate	1.06	10 cm	
5	Glufosinate	0.71	5 cm	2400
	S-metolachlor	1.06	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
6	Fomesafen	0.21	PRE	2430
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
7	Fomesafen	0.28	PRE	2330
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
8	Fluometuron	1.12	PRE	2370
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
9	Prometryn	1.12	PRE	2620
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; cm, centimeter; PRE, preemergence.

Table 2.9 cont. Field study 2 seedcotton yield averaged across locations and years. [a]
(P = 0.1272)

Treatment number	Herbicide	Rate	Palmer amaranth application timing	Cotton Yield
		kg ai/ha		kg/ha
10	Flumioxazin	0.036	PRE	1860
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
11	Diuron	0.56	PRE	2400
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
12	Pendimethalin	1.12	PRE	2590
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	
	Glufosinate	0.71	5 cm	

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; cm, centimeter; PRE, preemergence.

Table 2.10 Visual estimates of Palmer amaranth control taken at 14 and 35 days after emergence and at harvest for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing	14 DAE	35 DAE	Pre-harvest
		kg ai/ha			%	
2	Fluometuron	1.12	PRE	99	98	96
	Glufosinate	0.57	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
3	Fomesafen	0.21	PRE	98	96	96
	Glufosinate	0.57	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
4	Diuron	1.12	PRE	99	96	99
	Glufosinate	0.57	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
5	Fluometuron	1.12	PRE	100	98	99
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence; DAE, days after cotton emergence.

Table 2.10 cont. Visual estimates of Palmer amaranth control taken at 14 and 35 days after emergence and at harvest for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing	14 DAE	35 DAE	Pre-harvest
		kg ai/ha			%	
6	Diuron	1.12	PRE	100	99	99
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
7	Fomesafen	0.21	PRE	100	99	99
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
8	Glufosinate	0.57	2-3 lf cotton	83	93	95
	Glufosinate	0.57	6-8 lf cotton			
	Glufosinate	0.57	12 lf cotton			
	Flumioxazin	0.054	Layby			
9	Glufosinate	0.57	2-3 lf cotton	79	93	91
	Glufosinate	0.57	6-8 lf cotton			
	Glufosinate	0.57	12 lf cotton			
	Fomesafen	0.21	Layby			

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence; DAE, days after cotton emergence.

Table 2.10 cont. Visual estimates of Palmer amaranth control taken at 14 and 35 days after emergence and at harvest for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing	14 DAE	35 DAE	Pre-harvest
		kg ai/ha			%	
10	Glufosinate	0.57	2-3 lf cotton	76	90	84
	Glufosinate	0.57	6-8 lf cotton			
	Glufosinate	0.57	12 lf cotton			
	Fomesafen	0.28	Layby			
11	Fluometuron	1.12	PRE	99	93	91
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Fomesafen	0.28	Layby			
12	Fluometuron	1.12	PRE	96	95	95
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Glufosinate	0.57	10 lf cotton			
	Glufosinate	0.57	Layby			
	Fomesafen	0.21	Layby			

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence; DAE, days after cotton emergence.

Table 2.10 cont. Visual estimates of Palmer amaranth control taken at 14 and 35 days after emergence and at harvest for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing	14 DAE	35 DAE	Pre-harvest
		kg ai/ha			%	
13	Fluometuron	1.12	PRE	100	98	99
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Prometryn + Trifloxysulfuron	2.1	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
14	Fluometuron	1.12	PRE	100	99	98
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Fomesafen	0.21	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
15	Fluometuron	1.12	PRE	100	99	99
	Glufosinate	0.57	4 lf cotton			
	S-metolachor	1.06	4 lf cotton			
	Fomesafen	0.28	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence; DAE, days after cotton emergence.

Table 2.10 cont. Visual estimates of Palmer amaranth control taken at 14 and 35 days after emergence and at harvest for field study 3. [a]

Treatment number	Herbicide	Rate	Application timing	14 DAE	35 DAE	Pre-harvest
		kg ai/ha			%	
16	Fluometuron	1.12	PRE	100	99	100
	Glufosinate	0.57	4 lf cotton			
	S-metolachlor	1.06	4 lf cotton			
	MSMA	2	10 lf cotton			
	Diuron	0.56	10 lf cotton			
	Glufosinate	0.57	Layby			
	Flumioxazin	0.054	Layby			
17	Glufosinate	0.57	2-3 lf cotton	93	96	97
	S-metolachlor	1.06	2-3 lf cotton			
	Glufosinate	0.57	6-8 lf cotton			
	Glufosinate	0.57	12 lf cotton			
	Flumioxazin	0.054	Layby			

Data were not subjected to formal analysis of variance.

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence; DAE, days after cotton emergence.

Table 2.11 Field study 3 seedcotton yield averaged across years. [a] (P = 0.002)

Treatment number	Herbicide	Rate	Application timing	Cotton Yield
		kg ai/ha		kg/ha
2	Fluometeron	1.12	PRE	1920
	Glufosinate	0.57	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
3	Fomesafen	0.21	PRE	1920
	Glufosinate	0.57	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
4	Diuron	1.12	PRE	2070
	Glufosinate	0.57	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
5	Fluometuron	1.12	PRE	2040
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
6	Diuron	1.12	PRE	1910
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	

LSD to compare trt 4 versus any other trt or to compare any pair that does not include trt 4 = 470

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence.

Table 2.11 cont. Field study 3 seedcotton yield averaged across years. [a] (P = 0.002)

Treatment number	Herbicide	Rate	Application timing	Cotton Yield
		kg ai/ha		kg/ha
7	Fomesafen	0.21	PRE	1750
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
8	Glufosinate	0.57	2-3 lf cotton	1660
	Glufosinate	0.57	6-8 lf cotton	
	Glufosinate	0.57	12 lf cotton	
	Flumioxazin	0.054	Layby	
9	Glufosinate	0.57	2-3 lf cotton	1370
	Glufosinate	0.57	6-8 lf cotton	
	Glufosinate	0.57	12 lf cotton	
	Fomesafen	0.21	Layby	
10	Glufosinate	0.57	2-3 lf cotton	1190
	Glufosinate	0.57	6-8 lf cotton	
	Glufosinate	0.57	12 lf cotton	
	Fomesafen	0.28	Layby	
11	Fluometuron	1.12	PRE	1640
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Fomesafen	0.28	Layby	
12	Fluometuron	1.12	PRE	1790
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Glufosinate	0.57	10 lf cotton	
	Glufosinate	0.57	Layby	
	Fomesafen	0.21	Layby	

LSD to compare tart 4 versus any other trt or to compare any pair that does not include trt 4 = 470

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; PRE, preemergence.

Table 2.11 cont. Field study 3 seedcotton yield averaged across years. [a] (P = 0.002)

Treatment number	Herbicide	Rate	Application timing	Cotton yield
		kg ai/ha		kg/ha
13	Fluometuron	1.12	PRE	1920
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Prometryn + Trifloxysulfuron	2.1	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
14	Fluometuron	1.12	PRE	1990
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Fomesafen	0.21	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
15	Fluometuron	1.12	PRE	1900
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	Fomesafen	0.28	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	

LSD to compare trt 4 versus any other trt or to compare any pair that does not include trt 4 = 470

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare;; lf, leaf; PRE, preemergence.

Table 2.11 cont. Field study 3 seedcotton yield averaged across years. [a] (P = 0.002)

Treatment number	Herbicide	Rate	Application timing	Cotton yield
		kg ai/ha		kg/ha
16	Fluometuron	1.12	PRE	2300
	Glufosinate	0.57	4 lf cotton	
	S-metolachlor	1.06	4 lf cotton	
	MSMA	2	10 lf cotton	
	Diuron	0.56	10 lf cotton	
	Glufosinate	0.57	Layby	
	Flumioxazin	0.054	Layby	
17	Glufosinate	0.57	2-3 lf cotton	1730
	S-metolachlor	1.06	2-3 lf cotton	
	Glufosinate	0.57	6-8 lf cotton	
	Glufosinate	0.57	12 lf cotton	
	Flumioxazin	0.054	Layby	

LSD to compare trt 4 versus any other trt or to compare any pair that does not include trt 4 = 470

[a] Abbreviations: kg, kilograms; ai, active ingredient; ha, hectare; lf, leaf; PRE, preemergence.

Resistance Screening and Control Options for Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) in Cotton (*Gossypium hirsutum*)

Summary

In 2007, 32 of the 66 Palmer amaranth accessions were at least 10% glyphosate-resistant. Of the 66 accessions tested, 24 were 0.5 to 5, 9 were 6 to 10, 22 were 11 to 24, 8 were 25 to 50, and 3 were 69 to 86% glyphosate-resistant in 2007. Two counties (Lee and St. Francis) had high frequency of glyphosate-resistant Palmer amaranth. Both counties contained accessions that were greater than 80% glyphosate-resistant. Data from this 2007 survey suggested a highly evolving population of Palmer amaranth statewide, in terms of resistance to glyphosate. Overall the levels of glyphosate resistance were highly variable at this time both within fields, counties and accessions. By 2009, there were 23 counties in Arkansas known to be infested with glyphosate-resistant Palmer amaranth (Meier et al. 2009; Norsworthy et al. 2008). Glyphosate-resistant Palmer amaranth is now present in all row cropping counties in Arkansas. This 2007 survey data captured a moment in time when glyphosate resistance was rapidly evolving in Arkansas row crop areas, but had not yet reached all counties and fields.

In field study 1, visible stunting of greater than 6% was noted with 5 of the 28 PPL treatments when averaged across year and location. The 5 treatments causing injury 21 DAE were fomesafen at 0.21 and 0.28 kg ai/ha, flumioxazin at 0.071 kg ai/ha, prometryn at 1.12 kg ai/ha, and pendimethalin at 1.12 kg ai/ha which caused stunting of 15, 12, 48, 6, and 13%, respectively. All 5 of the treatments having injury 6 to 48% were applied at the 0 day prior to plant (DPP) timing.

At 7 days after emergence (DAE) of the cotton, fomesafen applied at 0.21 and 0.28 kg ai/ha, flumioxazin at 0.071 kg ai/ha, prometryn at 1.12 kg ai/ha, diuron at 0.56 kg ai/ha, and

pendimethalin at 1.12 kg ai/ha applied at 21, 14, 7, and 0 DPP all controlled Palmer amaranth 90 to 100%. At 14 DAE fomesafen applied at 0.21 kg ai/ha 7 and 21 DPP, fomesafen applied at 0.28 kg ai/ha 7 DPP flumioxazin at 0.071 kg ai/ha 7, 14, and 21 DPP and diuron at 0.56 kg ai/ha 14 and 21 DPP controlled Palmer amaranth 95 to 98%.Cotton yield by timing (21, 14, 7, and 0 DPP) was 2940, 2910, 2850, and 2560 kg/ha, respectively.

In field study 2, seven of the 11 systems provided season-long Palmer amaranth control of 90 to 93%, with little variation in year or location. The systems that contained preemergence herbicides provided Palmer amaranth control equal to those without. Fomesafen at 0.28 kg ai/ha, fluometuron at 1.12 kg ai/ha, flumioxazin at 0.036 kg ai/ha, diuron at 0.56 kg ai/ha, and pendimethalin at 1.12 kg ai/ha applied PRE followed by three applications of glufosinate at 0.71 kg ai/ha applied to 5 cm Palmer amaranth provided 90 to 93% control. Although glufosinate alone provided good Palmer amaranth control, there is no resistance management benefit from a herbicide program with a single mode of action. Preemergence and other residual herbicides are a necessity for good resistance management. The best herbicide program is the one that provides good Palmer amaranth control and has resistance management benefits. The highest numerical yields were provided by prometryn or pendimethalin at 1.12 kg ai/ha PRE followed by three consecutive applications of glufosinate at 0.71 kg ai/ha applied 5 cm and three consecutive applications of glufosinate at 0.71 kg ai/ha applied to 5 cm Palmer amaranth which yielded 2620, 2590, and 2550 kg/ha of seed cotton respectively. The seedcotton yields in study 2 were average to above average for Arkansas.

In field study 3, 15 herbicide systems out of 16 provided 91 to 100% control of palmer amaranth season long, with little variation in year and location. Glufosinate at 0.57 kg ai/ha applied at 2 to 3, 6 to 8, and 12-leaf cotton followed by fomesafen at 0.28 kg ai/ha applied at layby was the only system that did not provide season-long control of Palmer amaranth. Fluometuron at 1.12 kg ai/ha followed by glufosinate at 0.57 kg ai/ha plus metolachlor at 1.06 kg ai/ha applied at 4 leaf cotton followed by MSMA at 2.26 kg ai/ha plus diuron at 0.56 kg ai/ha applied to 10 leaf cotton followed by glufosinate at 0.57 kg ai/ha plus flumioxazin at 0.054 kg ai/ha at layby provided a yield of 2300 kg/ha of seed cotton.

The data generated in this research were instrumental in providing herbicide recommendations for the cotton producers of Arkansas and were used in the development of recommendations in the Extension publication MP-44. The data obtained from study 1 provided critical information which supported the 24c label for fomesafen (Reflex) use in Arkansas cotton. This data supported the preplant timing being adjusted from 21 DPP to 14 DPP and eventually led to further refinements in the full section 3 label recommendations which are based on rainfall and soil type.

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